BIMONTHLY REPORT

on

DEVELOPMENT OF PROCEDURES FOR WELDING 2-INCH-THICK TITANIUM-ALLOY PLATE

to

BUREAU OF NAVAL WEAPONS
DEPARTMENT OF THE NAVY

June 30, 1961
Contract No. NOw-60-0390-c

by

R. L. Koppenhofer, W. J. Lewis, G. E. Faulkner,
and P. J. Rieppel

61-4-6
NOX

BATTELLE MEMORIAL INSTITUTE
505 King Avenue
Columbus 1, Ohio

Battelle Memorial Institute

505 KING AVENUE COLUMBUS 1, OHIO

August 11, 1961

Department of the Navy
Bureau of Naval Weapons
Materials Division
Washington 25, D. C.

Attention RRMA-21

Dear Sir:

Contract No. NOw-60-0390-c

We are enclosing 13 copies (one of which is reproducible) of the sixth bimonthly report covering research on "Development of Procedures for Welding 2-Inch-Thick Titanium-Alloy Plate", which is being conducted under the above contract. The remaining copies of the report are being distributed according to the enclosed distribution list.

Very truly yours,

P. J. Rieppel
Chief
Metals Joining Division

PJR/bla
Enc. (14)

cc: Mr. C. G. Jacobsen (letter only)
ONR Resident Representative

DEDICATED TO THE ADVANCEMENT OF SCIENCE

DISTRIBUTION LIST

Mr. R. F. Malone
Crucible Steel Corporation
Midland, Pennsylvania

Mr. T. R. Gray
Assistant Chief Metallurgist
Aerospace Division
Boeing Aircraft Corporation
Seattle, Washington

Mr. Robert Wichser
Republic Aviation Corporation
Farmingdale, Long Island, New York

Mr. L. P. Spalding
North American Aviation, Inc.
International Airport
Los Angeles 45, California

Mr. W. H. Sharp, Metallurgist
Pratt & Whitney Aircraft Corporation
East Hartford 8, Connecticut

Mr. H. R. Ogden
Defense Metals Information Center
Battelle Memorial Institute
505 King Avenue
Columbus 1, Ohio

Mr. Howard Middendorp
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Mr. S. V. Arnold
Physical Metallurgy Division
Watertown Arsenal Laboratory
Watertown, Massachusetts

Mr. S. R. Carpenter
Producibility Supervisor
Mail Zone 6-148
Convair Division of General Dynamics Corporation
San Diego 12, California

North American Aviation, Inc.
Columbus, Ohio
Attn: Mr. Paul Maynard

Mr. J. Sessler
Metallurgical Research Laboratories
Syracuse University Research Institute
Syracuse, New York

Dr. George Gerard
Professor of Aeronautical Engineering
New York University
New York 53, New York

Commander, Headquarters
Air Materiel Command
Wright-Patterson Air Force Base, Ohio
Attn: MCFRM, Mr. Robert Jamison

Dr. D. J. McPherson, Manager
Metallurgical Research Department
Armour Research Foundation
10 West 35th Street
Chicago 16, Illinois

Mr. L. L. Gould
Staff Metallurgist
Materials Advisory Board
National Research Council
2101 Constitution Avenue, N. W.
Washington 25, D. C.

Mr. Carl Hartbower
Physical Metallurgy Division
Watertown Arsenal Laboratory
Watertown, Massachusetts

Mr. A. Hurlich
Engineering Materials Group
Mail Zone 595-2-41a
Convair Astronautic
Division of General Dynamics Corporation
San Diego 12, California

Grumman Aircraft Engineering Corporation
Bethpage, Long Island, New York
Attn: Mr. F. K. Drumm

Vought Aeronautics Corporation
Dallas, Texas
Attn: Mr. W. H. Sparrow

DISTRIBUTION LIST
(Continued)

Reactive Metals Inc.
Niles, Ohio
Attn: Mr. S. E. Seagle

Republic Steel Company
Massillon, Ohio
Attn: Mr. E. O. Mattes

David Taylor Model Basin
Carderock, Maryland
Attn: Mr. A. Wilner

Commanding Officer
Diamond Ordnance Fuse Laboratory
Washington 25, D. C.
Attn: Tech. Ref. Sec.

Chief, Bureau of Ships (Code 634B)
Department of the Navy
Washington 25, D. C.

Naval Research Laboratory
Washington 25, D. C.

National Aeronautical & Space Adm.
1520 H Street, N. W.
Washington 25, D. C.

Chief, Bureau of Ships (Code 442)
Department of the Navy
Washington 25, D. C.

Commanding General
Ordnance Corps
Detroit Arsenal
Centerline, Michigan
Attn: ORDMC-REMIL

Department of Commerce, Business
Defense Supply Agency
Washington 25, D. C.
Attn: Mr. H. Cullen

Titanium Metals Corporation of America
233 Broadway
New York 7, New York
Attn: Mr. W. W. Minkler

Mr. John H. Garrett
Chief, Materials Division
Office of the Director of Defense
Research and Engineering
The Pentagon
Washington 25, D. C.

Commanding Officer
Naval Air Material Center
Aeronautical Materials Laboratory
Philadelphia 12, Pennsylvania

Chief, Bureau of Ships [Code 341(A)]
Department of the Navy
Washington 25, D. C.

Office of Naval Research (Code 423)
Washington 25, D. C.

Aerospace Industries Association
7660 Beverly Boulevard
Los Angeles 36, California
Attn: Mr. H. D. Moran

Electric Boat Corporation
General Dynamics Corporation
Groton, Connecticut
Attn: Mr. Ray Sopher

Mr. T. J. Griffin
Bureau of Ships
Department of the Navy
Washington, D. C.
Code 634-B, Room 3628

TABLE OF CONTENTS

DEVELOPMENT OF PROCEDURES FOR WELDING 2-INCH-THICK TITANIUM-ALLOY PLATE

Research is being conducted to develop procedures for welding thick titanium-alloy plates. This research is part of an over-all program to evaluate thick titanium-alloy plate for use in deep-diving submarines. Weldments that have high strength in combination with good ductility and toughness are required for submarine hulls. The specific objectives of the research are to develop procedures to:

(1) Obtain sound ductile welds in 2-inch-thick plate

(2) Obtain joint efficiencies of 100 per cent

(3) Obtain satisfactory toughness in weldments

The following is a list of welds made prior to this report period. These welds were made in 30-inch-long, 2-inch-thick titanium-alloy plates:

Base Plate	Filler Wire	Heat Input, joules/inch
Ti-6Al-4V	Ti-6Al-4V	45,000
Ti-6Al-4V	Ti-6Al-4V	21,000
Ti-6Al-4V	Ti-5Al-2.5Sn	45,000
Ti-6Al-4V	A-55	45,000
Ti-5Al-2.5Sn	Ti-5Al-2.5Sn	45,000
Ti-5Al-2.5Sn	Ti-5Al-2.5Sn	27,000
Ti-5Al-2.5Sn	Ti-6Al-4V	45,000
Ti-5Al-2.5Sn	A-55	45,000
A-70	A-55	45,000
A-70	Ti-6Al-4V	45,000

In addition to these, Lehigh and NRL restraint tests were made on each of the three base plates, using filler wire that matched the composition of the base plate. Cracking has not been a problem in any of these welds.

Joint efficiencies of at least 100 per cent were obtained for all welds except those made with A-55 filler wire. Notch toughness of all weld metals in general was equal to, or greater than, that of the base plate.

In addition, prior to this report period, a weld was deposited manually in 1/2-inch-thick Ti-6Al-4V base plate, using a Ti-6Al high-purity-alloy filler wire. The amount of filler material was limited so that only enough weld metal for notch-toughness data was obtained. The notch toughness of this weld was the best obtained to date. Hardness data were obtained for this weld and are presented in this report.

During this report period, the Ti-13V-11Cr-3Al base plate was received and mechanical-test data obtained. A weld was made in 30-inch long, 2-inch-thick Ti-13V-11Cr-3Al plate using filler wire that matched the composition of the base plate. In addition, Lehigh and NRL restraint tests were made in this base plate using matching filler wire.

During this report period, an effort was made to determine the nil-ductility temperature (NDT) for the titanium alloys being studied. This report covers the period from April 30 to June 30, 1961.

SUMMARY

The Ti-13V-11Cr-3Al base plate was received during this report period. The impact properties of this base plate were very poor. Lehigh and NRL restraint tests were made on this alloy using filler wire that matched the composition of the base plate. No cracking was encountered in these welds. In addition, a 30-inch-long weld was made in 2-inch-thick Ti-13V-11Cr-3Al plate using filler wire that matched the composition of

the base plate. Weld-metal ultimate and yield strengths were somewhat lower than those of the base plate. Elongation of the weld metal was higher than that of the base plate in the transverse direction but lower than that of the base plate in the longitudinal direction. Impact properties of the weld metal were very low, but were similar to those of the base plate.

Hardness data obtained for the weld made in Ti-6Al-4V base plate using Ti-6Al high-purity filler wire were lower than for any weld made to date except for those made with A-55 filler wire. Vacuum-fusion analysis of this weld showed very low oxygen and hydrogen contents.

Studies also were made during this report period in an effort to establish drop-weight testing procedures for the weld metal and alloys being used in the program. Testing procedures standardized for steel specimens were used in initial tests. The brittle weld deposit was made using procedures developed in work done at the David Taylor Model Basin on 1-inch-thick titanium-alloy specimens. Nil-ductility temperatures that correlated with the Charpy vee-notch energy and lateral expansion curves were not obtained with these procedures. Additional work is planned to find a brittle weld deposit that will give satisfactory data.

A summary of all welds made to date in this program is given in Table 1.

WELDING AND TESTING PROCEDURES

The 30-inch-long weld and the restraint tests welds were made in an argon-filled chamber. A constant-potential power source connected for reverse polarity was used to supply the welding current. All filler wire was 1/16 inch in diameter and was cleaned in acetone prior to welding.

TABLE 1. SUMMARY OF ALL DATA OBTAINED TO DATE[a]

Material	Filler Metal	Heat Input, joules per inch	Composition, per cent									Ultimate Tensile Strength, 1000 psi		Tensile Yield Strength, 1000 psi		Elongation in 2 Inches, per cent		Reduction in Area, per cent		Notch Toughness[b], ft-lb			
			Al	V	Sn	Cr	Fe	C	N	H_2	O_2	Long.	Trans.	Long.	Trans.	Long.	Trans.	Long.	Trans.	Room Temp	0 F	–40 F	–80 F
										Ti-6Al-4V													
Base metal	–	–	6.13	4.16	–	–	0.10	0.01	0.011	0.0054	0.121	132	134.5	115	119	11	8	21	16	21	20	18	16
Filler wire	–	–	6.78	4.06	–	–	0.11	0.01	0.011	0.0150	0.112	–	–	–	–	–	–	–	–	–	–	–	–
Weld metal	Ti-6Al-4V	45,000	6.26	4.16	–	–	0.11	0.02	0.011	0.0046	0.131	144	135	128	(c)	6	(c)	9	(c)	20	17.5	18	16.5
Weld metal	Ti-5Al-2.5Sn	45,000	5.58	1.22	2.30	–	0.32	0.04	0.011	0.0096	0.143	133.5	137.5	131	(c)	11	(c)	19	(c)	21.5	15	16.5	14
Weld metal	A-55	45,000	1.75	1.05	–	–	0.10	0.03	0.024	0.0042	0.133	93	104	83	92	17.5	6	39	29	40	32	26	21.5
Weld metal	Ti-6Al-4V	21,000	6.28	4.08	–	–	0.11	0.04	0.012	0.0092	0.105	148	138.5	133	(c)	5	(c)	10	(c)	18	17.5	14.5	15
Weld metal	Ti-6Al	–	–	–	–	–	–	–	–	0.0042	0.070	–	–	–	–	–	–	–	–	36.5	–	–	38.5
										Ti-5Al-2.5Sn													
Base metal	–	–	5.38	–	2.43	–	0.12	0.07	0.018	0.0027	0.154	136	136.5	128.5	131.5	13	4	25	11	13	10	9	8
Filler wire	–	–	6.15	–	2.57	–	0.4	0.02	0.013	0.029	0.100	–	–	–	–	–	–	–	–	–	–	–	–
Weld metal	Ti-5Al-2.5Sn	45,000	5.09	–	2.60	–	0.23	0.05	0.015	0.0113	0.084	138	137	125	(c)	8	(c)	12	(c)	18	15	13	11
Weld metal	Ti-5Al-2.5Sn	27,000	5.35	–	2.58	–	0.37	0.04	0.013	0.0192	0.157	–	–	–	–	–	–	–	–	18	14	15	12.5
Weld metal	Ti-6Al-4V	45,000	5.95	3.06	1.70	–	0.12	0.02	0.012	0.0110	0.119	141	131	127	(c)	11	(c)	16	(c)	10	9	9	6.5
Weld metal	A-55	45,000	1.13	–	0.63	–	0.11	0.06	0.016	0.0067	0.169	87	–	76.5	–	21	–	34	–	25.5	22	22.5	18.5
										A-70													
Base metal	–	–	–	–	–	–	0.09	0.03	0.007	0.0073	0.317	97	98	80.5	88	27	25	54	60	12	9.5	12.5	8
Filler wire	–	–	–	–	–	–	0.12	0.01	0.014	0.0059	0.148	–	–	–	–	–	–	–	–	–	–	–	–
Weld metal	A-55	45,000	–	–	–	–	0.11	0.03	0.013	0.0060	0.177	82.5	–	69	–	24	–	44	–	17	13	14	13
Weld metal	Ti-6Al-4V	45,000	4.82	3.26	–	–	0.10	0.04	0.011	0.0090	0.17[illegible]	134	98	120	(c)	8.5	(c)	15.5	(c)	26.5	25	21.5	19
										Ti-13V-11Cr-3Al													
Base metal	–	–	3.24	13.4	–	10.7	0.18	0.022	0.027	0.0078	0.0779	130.5	132.5	129	130	18	8	41.5	34	4.5	4.5	5	–
Filler wire	–	–	3.16	13.5	–	10.7	0.17	0.01	0.026	0.0049	0.142	–	–	–	–	–	–	–	–	–	–	–	–
Weld metal	Ti-13V-11Cr-3Al	45,000	3.12	13.3	–	10.6	0.16	0.013	0.027	0.0068	0.0875	124.5	130	120	(c)	14.5	(c)	22	(c)	4	3	4	–

(a) All tensile values are averages of two tests.
(b) Base-metal impact properties are averages of two tests for Charpy bars taken in three directions with respect to the rolling direction. Weld-metal impact properties are averages of two tests.
(c) Transverse tension specimens failed in the base metal.

A 45-degree double-vee-type joint with a 1/8-inch land was used for the 30-inch-long weld. All joints were cleaned in acetone and pickled in a 40 per cent HNO_3, 2 per cent HF, and 58 per cent water solution prior to welding. The welding conditions that were used are shown in Table 2.

TABLE 2. WELDING CONDITIONS USED IN MAKING WELDS

Type of Weld	Filler Wire	Weld Travel Speed, ipm	Wire Feed Speed, ipm	Arc Voltage, volts	Weld Current, amperes	Heat Input, joules/inch	Contact-Tube-to-Work Distance, inch	Interpass Temperature, F	Number of Passes
30 inch	Ti-13V-11Cr-3Al	15	450	32	365	45,000	7/8	120-200	10
Lehigh	Ti-13V-11Cr-3Al	20	450	33	320	32,000	1	--	1
NRL	Ti-13V-11Cr-3Al	20	450	33	320	32,000	1	--	1

Standard 0.505-inch-diameter tension specimens and standard Charpy vee-notch impact specimens were used to obtain tensile and impact data.

Side-bend specimens 6 inches long, 1-1/2 inches wide, and 3/16 inch thick were used to obtain bend ductility. Bend tests were made by bending the specimens around dies of different radii until a crack was observed. The radii decreased from 2 to 1-1/2 inches, and then 1/4- to 3/4 inch and by 1/16-inch intervals down to a zero radius. The minimum bend radius was taken as the radius of the smallest die that the specimen passed without cracking.

Hardness data were obtained using a Vickers diamond pyramid hardness testing machine with a 10-kg load.

The equipment used for drop-weight tests consisted of a 130-pound weight that could be dropped from a maximum height of 15 feet (1950 ft-lb). Specimens 1-1/2 inches thick were prepared by machining from the 2-inch-thick plate. Smaller specimens used in some tests (5/8 by 2 by 5) were prepared by sawing. The brittle weld bead was about 3 inches long with about 1/16-inch penetration The weld bead was notched with a hand grinder to a depth of 0.07 inch above the surface of the specimen.

RESULTS AND DISCUSSION

During this report period, welds were evaluated in the all-beta Ti-13V-11Cr-3Al alloy made with matching filler wire, and attempts were made to obtain the nil-ductility temperature of the base metals used in this program.

Mechanical Properties

All tensile and bend-test data obtained for the weld in Ti-13V-11Cr-3Al are listed in Table 3. The base-metal tensile and bend-test data are given for comparison. The weld-metal ultimate and yield strengths are lower than those of the base plate for the all weld-metal longitudinal specimens. However, the transverse weld-metal tensile specimens failed in the base metal. Examination of these transverse weld-metal specimens showed that one of the specimens might have failed in the heat-affected zone, but the other failed away from the weld in the base metal. The elongation of the weld metal is lower than that of the base plate in the longitudinal direction but higher than that of the base plate in the transverse direction. The bend ductility of the base plate was better than that of the weld metal. In fact, the bend ductility of the Ti-13V-11Cr-3Al base plate was better than that of either the Ti-6Al-4V (4T) or the Ti-5Al-2.5Sn (5.5T) base plates.

The impact properties of the Ti-13V-11Cr-3Al base plate and weld metal are listed in Table 4. Several impact tests showed that the base plate and weld metal had very low notch toughness. In an attempt to improve the notch toughness, a number of the Charpy bars were solution heat treated in an argon atmosphere (1450 F for 1/2 hour, air cool) prior to impact testing. No significant improvement in notch toughness was noted, as shown in Table 4.

TABLE 3. TENSILE AND BEND-TEST DATA FOR WELD MADE IN Ti-13V-11Cr-3Al BASE PLATE USING MATCHING FILLER WIRE(a)

	Base Metal		Weld Metal	
	Long.	Trans.	Long.	Trans.
Ultimate Tensile Strength, ksi	130.5	132.5	124.5	130(b)
Tensile Yield Strength(c), ksi	1[illegible]9	130	120	(b)
Compressive Yield Strength, ksi	121	122	--	--
Elongation in 2 Inches, per cent	18	8	14.5	(b)
Reduction in Area, per cent	41.5	34	22	(b)
Minimum Bend Radius, T	2.5	2.5	--	5.5->10

(a) All tensile properties are average of two tests.
(b) Weld-metal transverse specimens failed in the base metal.
(c) Yield strength taken at 0.2 per cent offset.

TABLE 4. CHARPY VEE-NOTCH IMPACT DATA FOR THE Ti-13V-11Cr-3Al BASE PLATE AND WELD METAL

	Notch Toughness, ft-lb, at Indicated Temperature, F				
	Room	0	-40	-60	-80
Base Metal(a)					
L	3.5	3.5	6.5	--	10(b)
	4	4	4.5(b)		
	5.5(b)	6(b)	5(b)		
T	3.5	4	6.5	--	3.5(b)
	2.5	3	3(b)		
	3.5(b)	5(b)	4(b)		
FT	5	5.5	6.5	--	3.5(b)
	7	3	4(b)		
	4	5.5	4(b)		
Weld Metal	4	2.5	5.5	--	6(b)
	3.5	3	3(b)		
	3.5(b)	3.5(b)	2.5(b)		

(a) L = notched parallel to rolling direction with notch perpendicular to top of plate.
T = notched perpendicular to rolling direction with notch perpendicular to top of plate.
FT = notched perpendicular to rolling direction with notch parallel to top of plate.
(b) Specimen solution heat treated prior to testing at 1450 F for 1/2 hour, air cool.

Hardness and Metallographic Studies

Hardness and metallographic studies were made on the weld in the Ti-13V-11Cr-3Al alloy. The hardness was as follows:

	Range	Average
Base metal	299 to 319	310
Heat-affected zone	306 to 319	313
Weld metal	292 to 330	296

Microstructures for the base metal, heat-affected zone, and weld metal in the Ti-13V-11Cr-3Al alloy are shown in Figures 1, 2, and 3, respectively. The base metal and heat-affected zones (Figures 1 and 2) had similar grain sizes. The weld metal (Figure 3) has extremely large grains which are typical of weld metals in this alloy.

Hardness data also were obtained for the manual weld made in Ti-6Al-4V base plate with Ti-6Al high-purity filler wire. These data are as follows:

	Range	Average
Base metal	306 to 342	324
Heat-affected zone	311 to 330	320
Weld metal	245 to 323	282

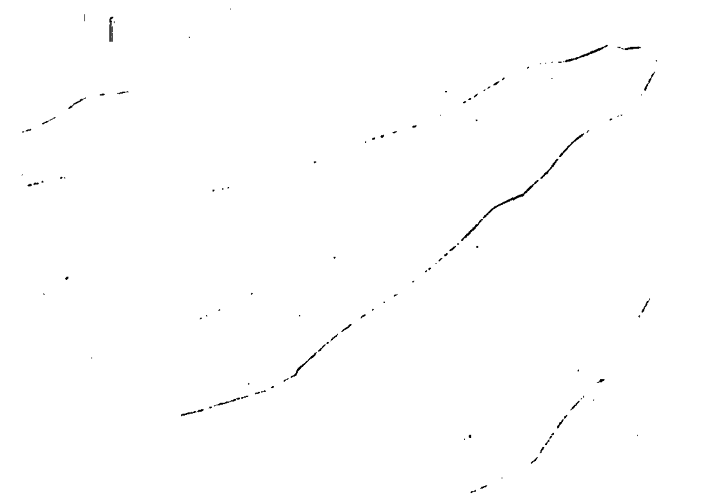
The hardness of this weld metal is lower than for any of the welds made to date except for those made with the A-55 filler wire. On the basis of previous hardness data, we would expect that this weld metal would not match the strength of the base metal. The microstructure of this weld metal is shown in Figure 4. The impact properties of this weld (Ti-6Al-4V base plate with Ti-6Al high-purity filler) were reported in Battelle's bimonthly report dated April 30, 1961 (38.5 ft-lb at -80 F).

100X 1.5HF, 3.5HNO_3, Balance H_2O N79918

FIGURE 1. MICROSTRUCTURE OF Ti-13V-11Cr-3Al BASE PLATE

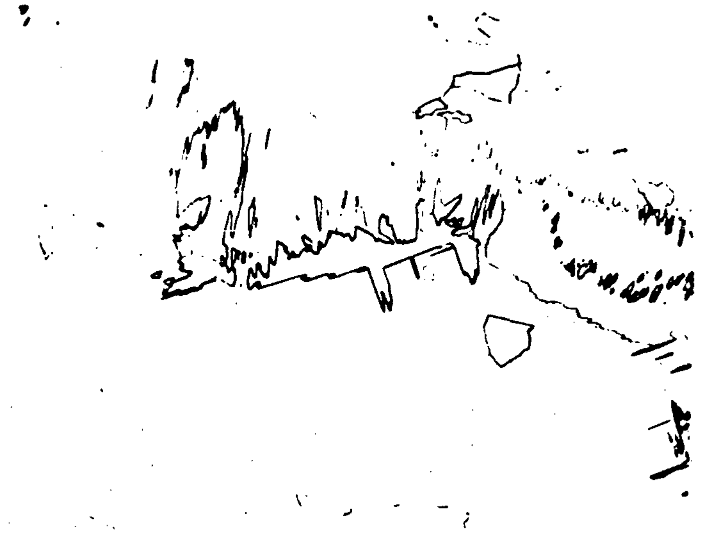
100X 1.5HF, 3.5HNO_3, Balance H_2O N79919

FIGURE 2. MICROSTRUCTURE OF HEAT-AFFECTED ZONE OF WELD MADE IN Ti-13V-11Cr-3Al BASE PLATE USING MATCHING FILLER WIRE



100X 1.5 HF, 3.5 HNO_3, Balance H_2O N79920

FIGURE 3. MICROSTRUCTURE OF WELD METAL OF WELD MADE IN Ti-13V-11 Cr-3Al BASE PLATE USING MATCHING FILLER WIRE



100X 1.5HF, 3.5HNO_3, Balance H_2O N80355

FIGURE 4. MICROSTRUCTURE OF WELD METAL MADE IN Ti-6Al-4V BASE PLATE USING Ti-6Al HIGH-PURITY FILLER WIRE

Chemical Analysis

The composition of the Ti-13V-11Cr-3Al base plate, filler wire, and of the weld made in this base plate using matching filler wire are as follows:

Material	Composition, per cent							
	V	Cr	Al	Fe	C	N	H_2	O_2
Base metal	13.4	10.7	3.24	0.18	0.022	0.027	0.0078	0.0779
Filler wire	13.5	10.7	3.16	0.17	0.01	0.026	0.0049	0.1420
Weld metal	13.3	10.6	3.12	0.16	0.018	0.027	0.0068	0.0875

The only element analysis that posed a problem was the oxygen content of the base metal. Three different analyses were made of the base plate for oxygen. The first analysis showed 0.0102 per cent oxygen. This analysis was extremely low and was in error. Two additional analyses showed 0.0685 and 0.0873 per cent oxygen. These figures also represent low oxygen contents in comparison with other base-plate materials being studied, and the reported figure is an average of these two values.

Oxygen and hydrogen analyses also were obtained for the manual weld made in Ti-6Al-4V base plate with Ti-6Al high-purity filler wire. An oxygen content of 770 ppm and a hydrogen content of 42 ppm were obtained. The low interstitial contents of this weld metal, it is believed, cause the high impact properties of this weld (38.5 ft-lb at -80 F).

Drop-Weight Tests

During this report period, tests were started in an effort to determine the nil-ductility temperature (NDT) for the base plates being studied. For these tests, 1-1/2-inch-thick by 3-1/2-inch-wide by 14-inch-long specimens were machined from the 2-inch-thick plate. Standardized testing procedures for this size steel specimen established by Puzak and Babecki* were used initially, i.e., 12-inch span and 0.2-inch anvil stop. Procedures for depositing the brittle crack-starter bead were taken from work done by Willner and Sullivan**. These procedures consisted of depositing a bead using A-70 filler wire at a heat input of about 18,000 joules per inch in a helium-nitrogen atmosphere. The bead was notched with a hand grinder to a depth 0.070 inch above the surface of the specimen prior to testing.

In an attempt to determine welding conditions for the brittle weld bead, welds were deposited on specimens 5/8 inch thick, 2 inches wide, and 5 inches long, which were then drop-weight tested. The following welding conditions were established:

Weld Travel Speed, ipm	30
Wire Feed Speed, ipm	515
Weld Current, amperes	290 to 300
Arc Voltage, volts	34
Contact-Tube-to-Work Distance, inches	1-5/8
Heat Input, joules per inch	20,000
Chamber Atmosphere, per cent	90He – $10N_2$

Using these welding conditions for the brittle weld bead, drop-weight tests were made on 1-1/2-inch-thick specimens machined from the Ti-6Al-4V and the Ti-5Al-2.5Sn base plates.

A 12-inch span was used for all specimens tested. Anvil stop distances of 0.2 inch (used for steel specimens) and 0.3 inch were tried. The brittle weld bead was cracked at the bottom of the notch in every test made.

The drop-weight test on the Ti-6Al-4V specimen using a 0.2-inch anvil stop showed only slight cracking in the base plate at 0 F. The second drop-weight test on the

*Puzak, P. P., and Babecki, A. G., "Normalization Procedures for NRL Drop Weight Test", Naval Research Laboratory Report 5220 (November 3, 1958).
**Willner, A. R., and Sullivan, V. E., Progress Report on "Metallurgical Investigation of Titanium Alloys for Application to Deep Diving Submarines", David Taylor Model Basin Report 1482 (December, 1960).

Ti-6Al-4V alloy was made using a 0.3-inch anvil stop at 0 F and only slight cracking was encountered in the base plate. Two tests also were made on the Ti-5Al-2.5Sn base plate but a 0.3-inch anvil stop was used in both of these tests. No cracking in the base plate was obtained in either of these tests.

When using the 0.3-inch anvil stop, the impact force was not great enough to deflect the specimens the total 0.3 inch. However, permanent deformation was noted in these specimens. Because the specimens were plastically deformed in these tests and no fractures were obtained, it is felt that the brittle weld deposit used is not satisfactory. Additional work is planned in an effort to obtain a satisfactory brittle weld bead.

CONCLUSIONS

The following conclusions can be drawn from the results obtained during this report period:

(1) The impact properties of the Ti-13V-11Cr-3Al base plate are poor. The weld made using Ti-13V-11Cr-3Al base plate and filler wire had:

(a) Notch toughness as good as that of the base plate

(b) Ultimate and yield strengths about 5 per cent lower than that of the base plate

(c) Elongation lower than that of the base plate in the logitudinal direction but higher than that of the base plate in the transverse direction

(d) Bend ductility considerably lower than that of the base plate.

(2) The low interstitial content of the weld made in Ti-6Al-4V base plate using Ti-6Al high-purity filler wire probably accounts for the low hardness and high impact properties of this weld.

FUTURE WORK

In the future it is planned to continue work on NDT determinations of the base plates in an effort to obtain a satisfactory brittle crack-starter bead. In addition, it is planned to make additional welds using high-purity filler materials.

Data are recorded in Battelle Laboratory Record Book Nos. 17387, 17955, pages 1 through 46, and No. 17956, pages 1 through 30.

RLK:WJL:GEF:PJR/bla